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HANNA KACIUBA-UŚCIŁKO, BARBARA KRUK, KRYSTYNA NAZAR,
JOHN E. GREENLEAF* and STANISŁAW KOZŁOWSKI

PROGRESSIVE ENHANCEMENT OF BODY TEMPERATURE RESPONSES TO CONSECUTIVE EXERCISE-BOUTS OF THE SAME INTENSITY IN DOGS**

Department of Applied Physiology, Medical Research Centre, Polish Academy of Sciences, Warsaw

Kaciuba-Uściłko, H., Kruk, B., Nazar, K., Greenleaf, J. E. and *Kozłowski, S.*: Progressive enhancement of body temperature responses to consecutive exercise-bouts of the same intensity in dogs. Acta physiol. pol., 1985, 36 (3): 165—174. Changes in rectal (T_{re}), muscle (T_m), and hypothalamic (T_{hy}) temperatures, plasma osmolality, and some intermediary metabolic variables were examined in dogs performing four successive exercise-bouts of the same intensity. During the rest-intervals separating the exercise-bouts body temperatures returned to initial levels and water losses were replaced. T_m and T_{re} responses to consecutive exercise-bouts were progressively increasing. Similar tendency was found in T_{hy} changes. Cardiac and respiratory frequencies attained the same levels in all four exercise-bouts, while blood lactate and FFA concentrations were increasing and blood glucose level was decreasing progressively. No changes in plasma osmolality was noted. Exercise-induced increases in T_m correlated positively with plasma FFA concentration (r = 0.68). Body temperature responses to exercise were reduced by beta-adrenergic blockade.

It is concluded that the enhancement of the thermal responses to consecutive exercise-bouts can be related to the metabolic action of catecholamines.

In man, during prolonged submaximal exercise with a constant load, a steady-state body-core temperature is seldom observed [18]. A progressive rise in core temperature has been attributed to several factors: total body dehydration [7, 9, 13]; changes in sodium, calcium and osmotic concentration in blood plasma and in the hypothalamus [7, 8, 19]; increase in metabolic rate resulting from impaired coordination of body limbs caused by fatigue; and possibly by altered action of calorigenic hormones (catecholamines, thyroxine, glucagon). Concentrations of these three hormones in blood increase during prolonged exercise [6, 11, 17].

* Dr John E. Greenleaf was a senior NIH post-doctoral fellow on leave from NASA Ames Research Center, Moffett Field, California 94035, USA.

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In dogs exercising at a constant load, there is an initial rapid increase in body temperatures (muscle, rectal, hypothalamic) during the first 30 min, followed by stabilization during the next 15—30 min. Then, there is a secondary gradual increase in temperatures usually within the second hour that continues to the point of exhaustion [3, 14].

It seemed worth while to find out whether the second phase of body temperature increase could be prevented by water supplementation and by introducing rest-intervals which enable full dissipation of heat accumulated in the body.

Thus, in the present work changes in rectal, muscle and brain temperatures, as well as in the plasma osmolality and in some intermediary metabolic variables (blood lactate, free fatty acid and glucose concentrations) were followed in successive 30 min exercise-bouts of identical intensity separated by rest periods long enough to lower body temperature to the pre-exercise levels. During each of these intervals the dogs were given water ad libitum. Besides, in the additional series of experiments β-adrenergic blockade with propranolol was applied to elucidate contribution of calorigenic action of catecholamines to thermal response to exercise.

MATERIAL AND METHODS

Male, mongrel dogs (14.4 to 21.0 kg) were maintained on a standard mixed diet. They were accustomed to running on a motor-driven treadmill but were not subjected to extensive endurance training. Three experimental series were performed. In each series the dogs performed four consecutive 30-min exercise-bouts (I, II, III, IV), at 1.3 m/s on a slope of 21%, separated by rest periods of 30 min that allowed all measured body temperatures to return to or even below their respective pre-exercise (bout I) resting levels. Before each test the dogs were deprived of food for 18—20 h, but they always had free access to drinking water, except during exercise.

In the first series (seven dogs), rectal (T_{re}) and hypothalamic (T_{hy}) temperatures were recorded continuously with thermocouples during the four exercise-bouts and rest periods, whereas thigh muscle temperature (T_m) was recorded with a needle thermocouple before each exercise-bout, immediately after exercise, and every 10 min during rest. To alleviate exercise-induced dehydration, the dogs were allowed to drink water *ad libitum* during each rest period. All experiments were conducted at an ambient temperature between 20° and 23°C and relative humidity between 50% and 60%. At least 2 weeks before starting the experiments, thermocouple guide tubes were implanted stereotaxically (under hexobarbital anesthesia) into the lateral preoptic area of the hypothalamus using coordinates A-23, L-3 and V-11 as described by Dua-Sharma, Sharma and Jacobs [5].

In the second series (seven dogs), T_{re} and T_m were recorded as before. Heart frequency (H_f) was mesured at 15-min intervals, using ECG chest electrodes, and respiratory frequency (R_f) was measured each 10 min with a resistance transducer placed on the thorax. Just before each exercise-bout and immediately after exercise, venous blood samples were taken from the cephalic vein through a catheter for determination of blood lactate (LA) concentration (Boehringer Mannheim GmbH Diagnostics), blood glucose concentration (Formognost, DDR), plasma osmolality (Fiske osmometer), and plasma free fatty acid (FFA) concentration [15].

In the third series, four dogs were injected i.v. with 0,25 mg/kg of propranolol (Polfa, Poland) after the first exercise bout. Blood samples were taken and T_{re}, T_m and H_f were measured as described previously.

The data were analyzed with Student's *t*-test for paired (dependent) samples; correlation and linear regression coefficients were calculated. The level of significance was at least $P < 0.05$. Nonsignificant differences were denoted by NS.

RESULTS

Changes in the muscle (T_m), rectal (T_{re}) and hypothalamic (T_{hy}) temperatures during 4 successive, 30-min exercise-bouts, as well as the rates of the temperature decreases during the periods of rest following each exercise are presented in Fig. 1.

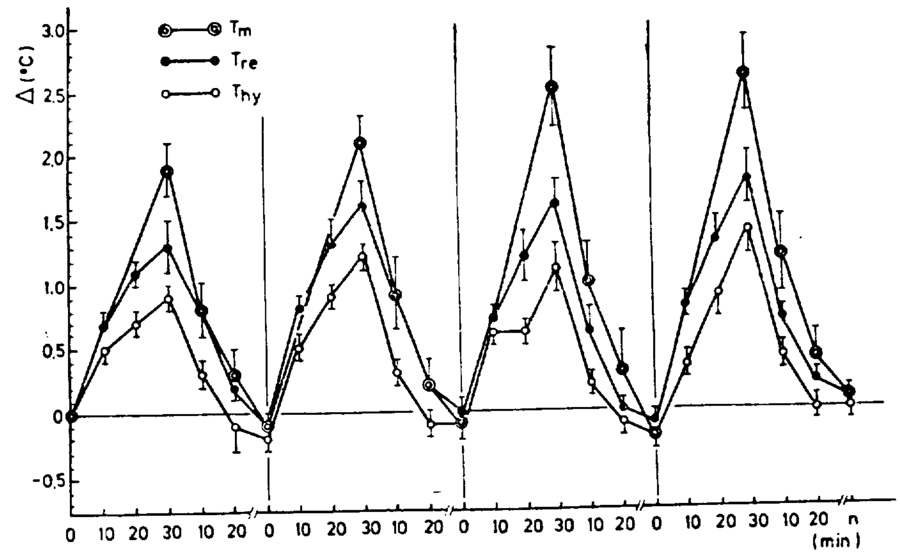

Fig. 1. Changes in muscle (T_m), rectal (T_{re}), and hypothalamic (T_{hy}) temperatures during four consecutive 30-min exercise-bouts of the same intensity and post-exercise rest intervals.

During the first exercise-bout T_m increased on the average by $1.9 \pm$ (SE) $0.2°C$, T_{re} by $1.3 \pm 0.2°$ and T_{hy} by $0.9 \pm 0.1°C$.

The increases in all the temperatures measured in further exercise-bouts of the same intensity were significantly higher in comparison with the first exercise.

The difference between the increases in T_m found in the first exercise-

-bout versus those in the 2nd, 3rd and 4th exercise-bouts were: $0.33 \pm \pm 0.11°C$ ($p < 0.02$), $0.69 \pm 0.18°C$ ($p < 0.02$), and $0.84 \pm 0.28°C$ ($p < 0.01$), respectively.

The increases in T_{re} at the end of the 2nd, 3rd and 4th exercise-bouts differed from that found during the 1st exercise by $0.29 \pm 0.07°C$ ($p < 0.01$), $0.37 \pm 0.11°C$ ($p < 0.02$) and $0.56 \pm 0.12°C$ ($p < 0.01$), respectively.

The differences between the increases in T_{hy} were significant only for the 2nd and 4th exercise-bouts, and they amounted to $0.38 \pm 0.03°C$ ($p < < 0.001$), and $0.62 \pm 0.15°C$ ($p < 0.01$).

During the recovery period after each exercise-bout, all the temperatures measured started to fall immediately after termination of exercise. The rate of T_m decrease was the highest and that of T_{hy} the lowest after all 4 exercise-bouts. Moreover, within each temperature measured the rate of the post-exercise decrease towards respective initial values was accelerated after successive exercise-bouts.

Basing on all the temperature data it was found that the rate of post-exercise temperature decreases depends on absolute values of the temperatures achieved at the end of exercise ($r = 0.441$, $n = 84$, $p < 0.001$).

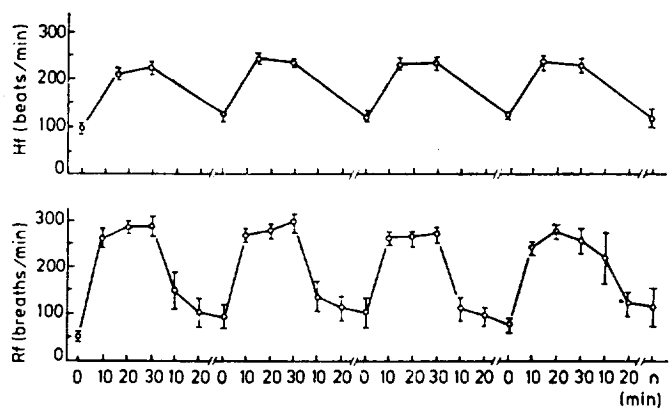

Fig. 2. Changes in cardiac frequency (H_f) and respiratory frequency (R_f) during four consecutive 30-min exercise-bouts, and post-exercise rest intervals.

Fig. 2 shows changes in cardiac frequency (H_f), and respiratory frequency (R_f) during successive exercise and post-exercise periods. The animals achieved similar values of H_f — on the average 227 ± 2 beats/min and R_f — on the average 274 ± 8 breaths/min in consecutive exercise-bouts. It should be mentioned, however, that during the rest-periods H_f did not return to the initial values, so the dogs started consecutive exercise-bouts with H_f elevated by approximately 22 beats/min above the initial level.

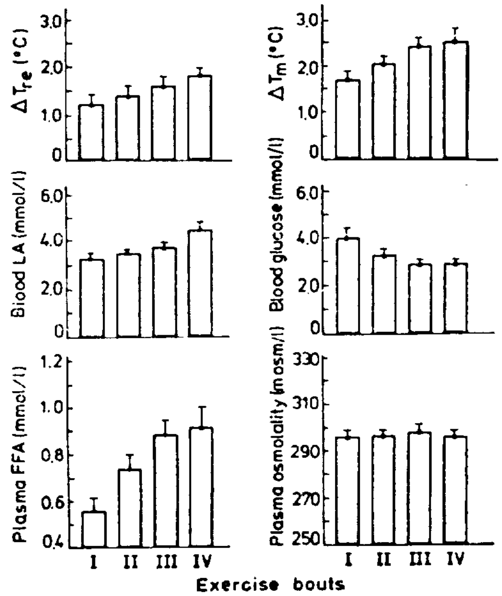

Fig. 3. Increases in rectal (T_{re}) and muscle (T_m) temperatures, blood metabolite concentrations, and plasma osmolality at the end of four consecutive, 30-min exercise-bouts of the same intensity.

Fig. 3. illustrates changes in T_{re} and T_m as well as alterations in blood lactate (LA), glucose, plasma FFA and osmolality occurring during 4 consecutive exercise-bouts. Similarly to the results obtained in the previous series of experiments, the exercise-induced increases both in T_m and T_{re} were the lowest in the 1st exercise-bout ($1.7 \pm 0.2°C$, and $1.2 \pm 0.2°C$, respectively) and the highest at the end of the 4th exercise-bout ($2.5 \pm 0.3°C$ and $1.8 \pm 0.2°C$, respectively).

Both blood LA concentration and plasma FFA level rose progressively during consecutive exercise-bouts in spite of the rest-periods separating the exercises. It should be pointed out, however, that during the periods of rest these variables failed to attain the initial levels. Blood glucose concentration decreased progressively during consecutive exercise--bouts, and the rest-periods did not prevent development of hypoglycemia.

Plasma osmolality did not change during the whole period of experiment.

To find out whether the described above progressive increases in the muscle and rectal temperatures in consecutive exercise-bouts can be attributed to any metabolic alterations, they were correlated with all the measured metabolic variables. A significant relationship was found only

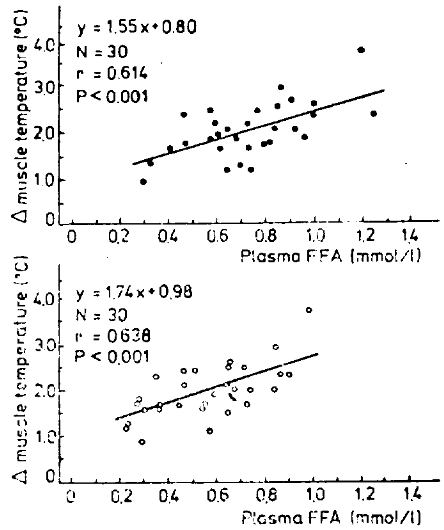

Fig. 4. A relationship between the increases in muscle temperature at the end of each exercise and plasma FFA concentration determined at the end (upper part) or at the beginning (lower part) of each exercise period.

between the muscle temperature achieved during exercise and the plasma FFA levels (Fig. 4).

Propranolol injected i.v. after termination of the first exercise-bout markedly reduced both T_{re} and T_m increases during successive exercise-bouts (Fig. 5). Cardiac frequency was by approximately 44 beats/min lower at the end of the second run and by 68 beats/min lower at the end of the third exercise-bout in comparison with control experiments without propranolol, whereas R_f did not show any significant differences.

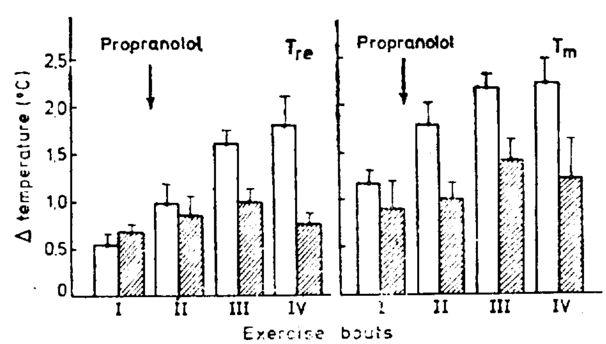

Fig. 5. Effect of propranolol given after the first exercise-bout on exercise-induced increases in rectal (T_{re}) and muscle (T_m) temperatures (white bars — control experiments, dashed bars — experiments with propranolol).

In the dogs injected with propranolol no increases in the plasma FFA levels were noted during consecutive exercise-bouts. Propranolol inhibited the increases in the blood LA concentration observed in control experiments. Only two out of 6 dogs were able to continue the 4^{th} exercise-bout to the end; the remaining animals terminated the exercise earlier with symptoms of complete exhaustion.

DISCUSSION

The present study demonstrated that exercise-induced increases in muscle temperature were the highest, in rectal temperature intermediate, whereas those in hypothalamic temperature the lowest. This is compatible with our previous data concerning changes in body temperatures in dogs performing continuous, prolonged exercise [14] as well as with the data reported by Clough and Jessen [4]. Contrary to Baker and Chapman [1] no decrease in the hypothalamic temperature at the beginning of exercise was observed.

The most striking result of the present investigations is the finding that in spite of the identical intensity of consecutive exercise-bouts, inducing similar cardiac and respiratory frequencies, the rate of the muscle temperature increases became progressively elevated (from 0.064°C/min in the first exercise to 0.089°C/min in the fourth exercise-bout). Similar, although not so much pronounced, tendency was also noted in case of rectal temperature. Hypothalamic temperature did not change with such regularity in consecutive exercise-bouts although its increases during further exercise-bouts were somewhat higher than during the first exercise.

During continuous, prolonged exercise some time-dependent heat storage may occur that would increase body temperature because of the cumulative effect of slight alterations in thermoregulatory control. The progressive increase of T_{m} and T_{re} during consecutive exercise-bouts in the present study cannot be explained by such a mechanism, since cumulative heat storage was prevented by use of rest-periods. Body dehydration and hyperosmotemia did not cause the increased temperature responses [13] since the dogs drank water in the rest-periods, and resting and exercise plasma osmotic concentrations were unchanged throughout the exercise-rest bouts.

Oxygen uptake was not measured in this study so it was not possible to correlate changes in body temperature with the metabolic rate during each exercise-bout. It seems likely, however, that the enhancement in temperature-responses to consecutive exercise-bouts may be directly related to the time-dependent changes in intermediary metabolism, As it was demonstrated the successive exercise-bouts differed in respect to blood glucose, lactate and FFA concentrations. The pattern of changes in these variables resembled that described during prolonged, continuous exercise in dogs [3]. Thus, the applied rest-intervals were too short for the recovery of exercise-induced biochemical changes.

It was found previously in preliminary experiments (unpublished data) that plasma noradrenaline (NA) concentration also increases progressively in spite of the rest-intervals. Both this finding and the progressively increasing plasma FFA level evidence that activity of the sympathetic system is gradually elevated. Similarly to the prolonged, continuous exercise the progressive stimulation of the adrenergic system may be related to the glucostatic mechanism activated in response to the exercise-induced depletion of carbohydrate stores [12, 16].

It may be presumed that the thermogenic effect of catecholamines in working muscles can be responsible for the augmented temperature responses to consecutive exercise-bouts, the more that a significant correlation was found between the increases in muscle temperature and the plasma FFA concentration. It should be emphasized that in dogs lipolysis during exercise is mainly stimulated by catecholamines [17]. So, both the lipolytic and thermal effects could be related to the same adrenergic mechanism. A direct effect of catecholamines on heat production in the dog skeletal muscle was described by Schmitt et al. [20]. Besides, an interaction of thyroid hormones and catecholamines might be taken into consideration as a possible mechanism of the enhanced thermal responses in consecutive exercise-bouts [10].

The role of the adrenergic system in determining the thermal response to exercise was further confirmed by the experiments with β-adrenergic blockade. Both the muscle and rectal temperature increases in subsequent exercise-bouts were considerably reduced by an injection of propranolol at the end of the first exercise.

In human subjects beta-adrenergic blockade with propranolol was found to increase the mixed venous blood temperature during exercise [2]. This effect has been attributed to the decreased cardiac output and subsequently smaller skin perfusion, resulting in impaired heat elimination. In dogs panting is the main avenue of heat dissipation so the propranolol-induced diminished skin blood flow may affect heat dissipation during exercise much less than in men, However, also in this species an increase in core and muscle temperature response to exercise after beta-adrenergic blockade might have been expected as a result of the presumably reduced muscle blood flow and bronchial constriction.

Contrary to these expectations the exercise-induced temperature increases were found to be considerably diminished in propranolol-treated dogs, suggesting that an inhibition of the metabolic action of catecholamines predominates the possible disturbances in heat elimination produced by propranolol.

In conclusion: the present data indicate that during repeated bouts of exercise performed with the same intensity muscle and core temperature become progressively elevated despite returning of these temperatures to initial levels during the rest-periods separating the exercise-bouts. It seems likely that the enhancement of thermal responses to consecutive exercise-bouts is, at least partly, related to the metabolic effects of catecholamines.

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Authors' address: Zakład Fizjologii Stosowanej, Centrum Medycyny Doświadczalnej i Klinicznej PAN, 00-730 Warszawa, Jazgarzewska 17.